PERFORMANCE INNOVATION LABORATORIES

FAILURE ANALYSIS OF DROP TESTS FOR CRANE TOL0801002

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Date: July 30, 2009	**Date: July 30, 2009**

CLIENT INFORMATION

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Revision History			
Revision	**Created by**	**Date**	**Short Description**
1	**Eva Kosiba**	**July 30, 2009**	**Initial Version**

EXECUTIVE SUMMARY

A set of 8 Crane/Nasa-DoD drop test vehicles were submitted to Celestica's Performance Innovation Laboratories for physical failure analysis. The samples were SMT assembled with Pb-free solder by the customer. A subset of the leaded components was then hand soldered (reworked) with SnPb solder by the customer. After drop testing only three of the leaded components had electrical failures, one was a non-reworked, one 1x reworked, and one part was 2x reworked. All Pb-free PBGAs (non-reworked) electrically failed by 20 drops at 500G. Twenty-three leaded components from various cards were selected by the customer for failure analysis and subjected to dye & pry testing. None of the components selected for dye & pry testing had electrical failures. Ten out of the 23 components that were dye and pry'd showed signs of mechanical fracture. All except 2 mechanical fractures inspected were in the laminate under the pad; pad cratering. Only two out of the 23 components showed signs of solder joint fractures. Based on the 23 components selected for dye & pry, there is no correlation between the number of reworks and the amount of mechanical damage. As well, this selection of components shows no difference in drop test performance between SnPb and Pb-free solder.

Fifteen components were also selected for cross-sectioning, three of which were electrical failures after drop testing. Five out of the 15 cross-sectioned joints were found to have some level of mechanical damage, pad cratering. For two of the electrically failing parts the root cause of the electrical failure was a trace break due to pad cratering. The other part failed due to solder fatigue fracture. The remaining 2 samples had pad cratering which did not sever the copper trace.

In this study, a total of three components were found to have some mechanical failure in the solder, one of these resulted in an actual electrical failure. In all of these cases, the solder used was SnPb reworked. No solder failures were observed in the lead free, non-reworked components. All mechanical failures in the Pb-free soldered components were the result of pad cratering. In this study only a small portion of the components were subjected to failure analysis. More of the components would need to be analyzed in order to increase confidence in the trends observed.

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1. INTRODUCTION

1.1 PRODUCT INFORMATION

Eight populated test boards were provided to Celestica. All 8 boards had an Electroless Nickel/Immersion Gold (ENIG) surface finish on Isola 370HR laminate, and were processed using a SAC305 reflow alloy and SN100C wave solder alloy. A number of components on each test board were then hand reworked by the customer using Kester 66/285 SnPb solder (a 63Sn 37Pb solder) either one or two times.

All 8 samples were then subjected to drop testing as summarized below in Table 1.

Board	Drop Force	Duration	Number of Drops
60	500 G	2.0 ms	20
81	500 G	2.0 ms	20
82	340 G	2.0 ms	10
	500 G	2.0 ms	10
83	500 G	2.0 ms	20
84	500 G	2.0 ms	20
85	500 G	2.0 ms	20
86	502 G	2.0 ms	20
87	340 G	2.0 ms	10
	500 G	2.0 ms	10

Table 1: Drop Test Summary

Further details on the drop tests can be found in “TOL0801002 Crane Drop Testing Report.doc”.

This report focuses on the failure analysis that was performed upon the completion of the drop tests. The focus is to compare the quality of the solder joint of components that were reworked using SnPb solder with those which were not reworked at all. Leaded components were examined in this report.

1.2 DESCRIPTION OF TEST

The following matrix is a summary of components which were evaluated using either the ‘Dye and Pry’ method or through cross sectioning as per agreement between Carol Handwerker (CRANE consultant) and Polina Snugovsky (CLS) on May 7, 2009.

Board	Analysis Performed	Samples for Analysis											
		CLCC-20		PDIP-20			QFN-20		TQFP-144				TSOP-50
60	Cross Sectioning									U34**			
	Dye & Pry						U15**	U27*			U57*	U58	
81	Cross Sectioning						U15*						
	Dye & Pry							U27**			U57*		U25*
82	Cross Sectioning							U27*			U57		
	Dye & Pry											U58*	
83	Cross Sectioning			U8**				U27**					
	Dye & Pry										U57*	U58	U25*
84	Cross Sectioning	U14											U25**
	Dye & Pry		U17**				U15**					U58*	
85	Cross Sectioning										U57*	U58	U25*
	Dye & Pry						U15*		U3				
86	Cross Sectioning			U8*	U30		U15**						
	Dye & Pry							U27*			U57		U25**
87	Cross Sectioning					U38							
	Dye & Pry						U15*	U27**				U58	U25*

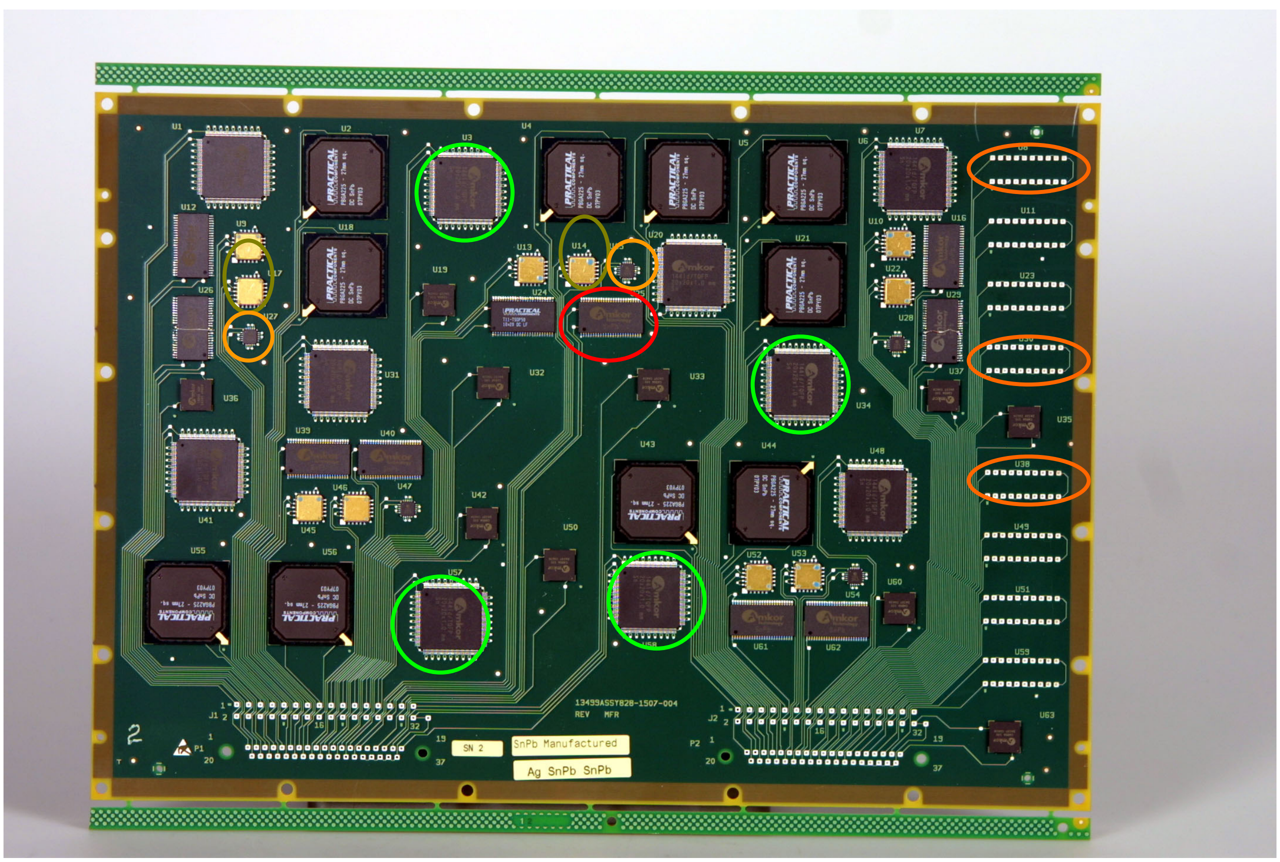
Table 2: Component Test Summary

** represents one rework performed*

*** represents two reworks performed*

Components that are underlined represent electrical failure which occurred during the drop test

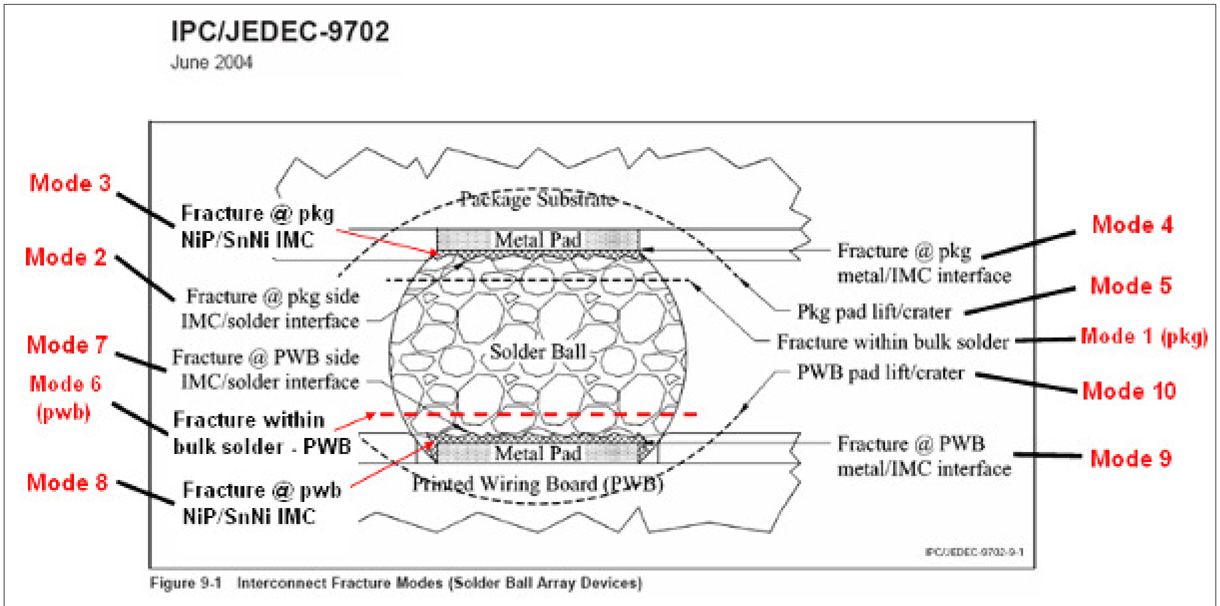
The location of the tested components is illustrated in figure 1.



All 8 boards were dyed using Dykem Steel Red Layout Fluid. After curing the dye, the components to be cross sectioned were then cut out from the rest of the board prior to any "prying" of the other components. This was done so as not to introduce any additional stress or failures within the cross sections.

Components evaluated through the dye and pry method were removed from the boards by first gluing shims of either a small PCB or aluminum to the top for added leverage. Once the glue had set, these shims provided sufficient leverage points for the prying of the components. Each separated lead, or solder joint was then evaluated for its failure mode using the possible failure modes described in Figure 2.

The components which were to be evaluated via cross sectioning where then potted (using LECOSET 100), ground, and polished according to Celestica's cross-sectioning procedure. They were then evaluated using an optical microscope.



NOTE: SEMEDX is required to distinguish between Failure Modes 2 & 3 as well as between Modes 7 & 8.

Figure 2: Mechanical Failure Modes

2. TEST SPECIFICATIONS

Name	Reference #	Level/Control
Dye and Pry Test	CELQ-001-PROC-1640	Rev.13
Cross-section Analysis	CELQ-001-PROC-450	Rev.15

3. INSTRUMENTATION

Description	Serial Number	Calibration Due Date
Olympus Stereo Microscope – SZX-12	n/a	n/a
Nikon MM-11 microscope	M7572	Calibrate before use

4. ANALYSTS

Name	Employee #	Title
Polina Snugovsky	07097117	Senior Metallurgist
Jason Bragg	07095810	Operations Engineering Advisor
Zohreh Bagheri	07006436	Metallurgical Analyst
Eva Kosiba	07005073	Operations Engineering Advisor

5. RESULTS AND COMMENTS

5.1 Dye and Pry

This test involved the dying of all boards after the drop tests were complete. The dye would penetrate any fracture that was present when placed in the vacuum chamber. The parts were then pry'd off of the board. At this point, all fracture surfaces where examined; the presence of dye on the fracture surface indicates that the fracture was not a product of the prying process but rather was already present and likely the result of the drop test.

There were no electrical failures observed during drop testing for any of the 23 components selected for the Dye and Pry failure analysis method. Mechanical failures were however observed on 10 of the 23 components (Table 3). One component (board 86, U27) was not sufficiently removed from the board after three attempts since the component itself fractured.

Board SN	Components That Were Dye & Pry Tested						
	CLCC-20	QFN-20		TQFP-144			TSOP-50
60		U15**	U27*		U57*	U58	
81			U27**		U57*		U25*
82						U58*	
83					U57*	U58	U25*
84	U17**	U15**				U58*	
85		U15*		U3			
86			U27*		U57		U25**
87		U15*	U27**			U58	U25*

Table 3: Dye and Pry Mechanical Failures

** represents one rework performed*
*** represents two reworks performed*

The locations highlighted in red in Table 3 represent mechanical failures which were evident due to the presence of dye within the fracture surface. Those in green did not show any dye penetration. At first glance it appears like there is a correlation between the number of reworks and the amount of mechanical failures, however, all the non-reworked (original Pb-free solder) chosen for analysis happen to be on the TQFP-144 part. This part has a very compliant lead shape, the component body itself is thin and as such is compliant and it has leads on all four sides for stress distribution. As a result, we believe the lack of any Pb-free (non-reworked) failures in this case is due to the package design, and not likely related to the solder strength or the fact that the non-reworked parts would experience less heat damage to laminate. Non-reworked components from the other package styles would need to dye & pry'd in order to further validate these ideas.

It is interesting to note that, as will be seen in the Cross-sectioning section below, the compliant TQFP-144 part can fail during drop testing, however, when it does, it failures in a solder joint fatigue manner rather than as a brittle solder intermetallic or pad cratering fracture mode.

board	component				
	CLCC-20	QFN-20		TQFP-144	TSOP-50
60		U15**	U27*		
81				U57*	U25*
83					U25*
84	U17**	U15**			
86					U25**
87		U15*			U25*

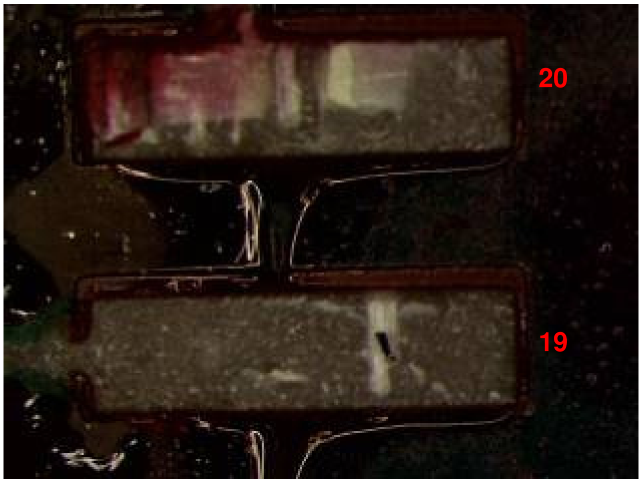
Table 4: Types of Failures in Dye and Pry Testing

** represents one rework performed*
*** represents two reworks performed*

The locations highlighted in red in Table 4 represent mechanical failures due to solder failure, those in orange represent mechanical failure due to pad cratering. Both of the solder failures occurred on parts which were reworked with leaded solder. Most of the observed mechanical failures were a result of pad cratering in which the solder pad and laminate separates from the board (Mode 10 in Figure 2). This would not necessarily lead to an immediate electrical failure as long as the copper trace is not broken. It could however be a reliability concern under thermal cycling and/or vibration stresses in the field.

For reference, the failing lead on all 23 dye & pry'd components is mapped out in the following MS-Excel "**TOL0801002 Crane drop test D&P failure scatter plot**.xls"

The SN 84, U17 CLCC-20 component and all of the TSOP-50s tested exhibited pad cratering at least at one of the corners. The TSOP-50 package is not as compliant as the TQFP and it is located and oriented on the board in such a way that it will receive the maximum board flexure and stress. All of these parts had been reworked with SnPb solder at least once. Figures 3 and 4 show the pad cratering visible on one of these corner leads (board 84, U17, pin 20).



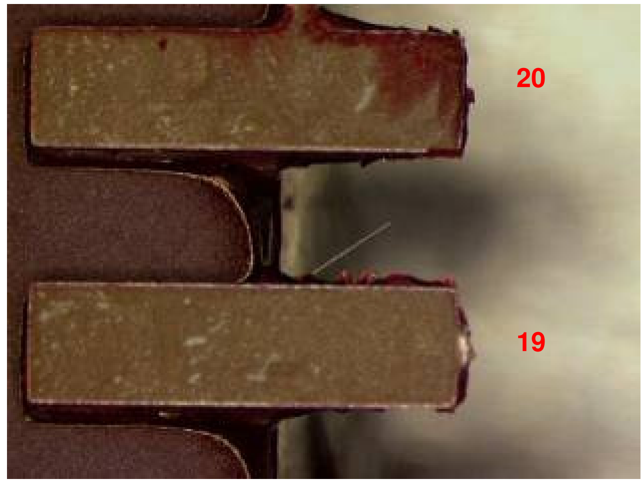
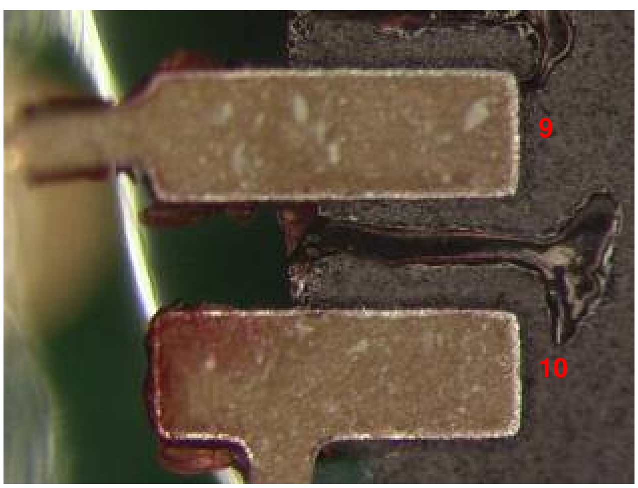


Figure 3: board 84, U17, pins 19-20, board side **Figure 4: board 84, U17, pins 19-20, comp. side**

Pin 20 of this CLCC-20 package, which is a corner pin located in the top left corner of the part., shows die penetration between the pad and the board along approximately 10% of the pad length. This indicates that pad cratering was present prior to prying the component off of the board. There appears to be little or no dye penetration on pin 19.

The CLCC-20 showed pad cratering occurring on only one corner lead. The TSOP-50 on the other hand showed a number of leads at each corner failing. The exception to this was board 86 which showed pad cratering on the two right hand corners of the board only.

Four of the eight QFN packages exhibited failure. These failures do not seem to correlate to whether or not the part was reworked or the number reworks which occurred. Two of the components (board 84, U15 and board 87, U15) showed pad cratering of one lead each. Figures 5 and 6 show a representative sample of this mechanical failure mode. The other two components that failed (board 60 U15 and U27) both showed failures at the intermetallic region and in one case, in the bulk solder. Figures 7 and 8 show a bulk solder fracture in lead #1 and an intermetallic fracture in lead #2.



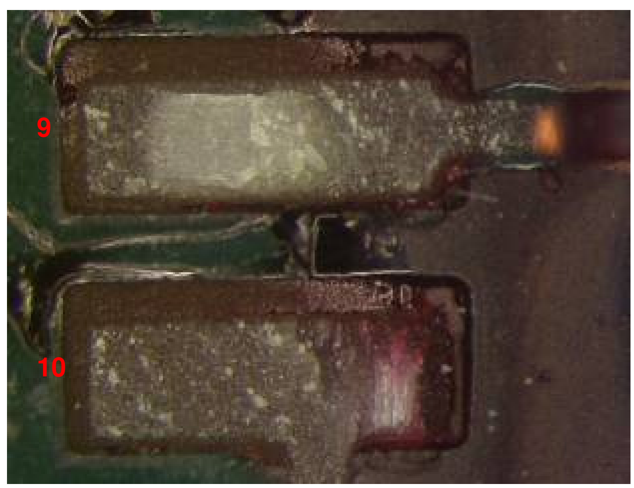


Figure 5: board 84, U15, pins 9-10, board side. **Figure 6: board 84, U15, pins 9-10, comp. side**

Pin 10 of this QFN-20 package, which is a corner pin, shows die penetration between the pad and the board along approximately one third of the pad length. This indicates that pad cratering was present prior to prying the component off of the board. There appears to be little or no dye penetration on pin 9. This example is typical of the pad cratering that was observed.

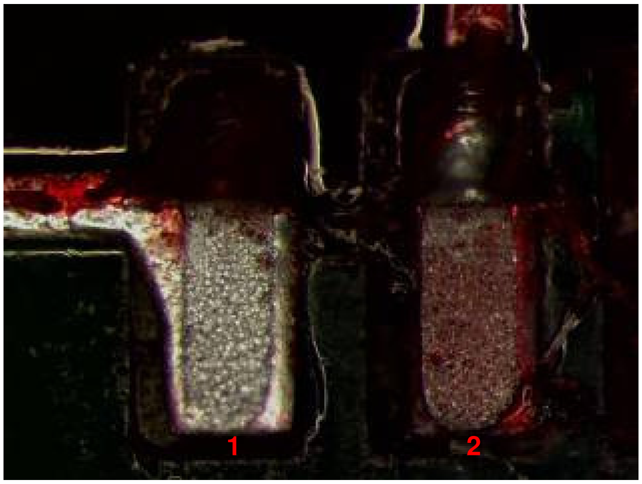


Figure 7: board 60, U27, pins 1-2, board side

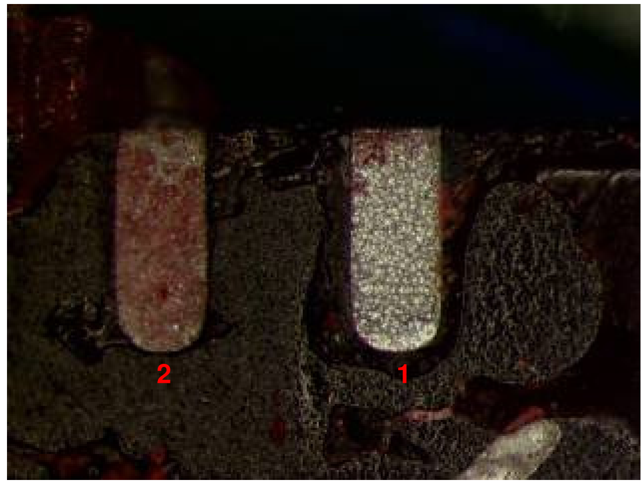


Figure 8: board 60, U27, pins 1-2, component side

Pin 1of this QFN-20 package, shows some evidence of die penetration through the bulk solder, indicating that a fracture was present prior to prying the component from the board. The penetration covers less then 25% of the solder surface. Pin 2 shows almost complete die penetration across the whole pin. The fracture appears to include the intermetallic surface.

Only one of the ten TQFP-144 exhibited full dye penetration of any lead. It showed signs of pad cratering in the bottom right corner (Figure 9 and 10). Of the other nine components tested, most of the solder joints survived; it was the leads themselves that broke during the prying portion of the dye and pry test.

Figure 9: board 81, U57, pins 109-112, board side

Figure 10: board 81, U57, pins 109-112, comp. side

Pins 109 to112 on this board were the only pins on any of the ten TQFP-144 package to exhibit mechanical failure. Dye penetration was observed over the entire surface of the pin. These pins are located at the bottom right hand corner.

A full mapping of the failures can be found in the attached spreadsheet entitled “TOL0801002 Crane drop test D&P failure scatter plot.xls”. Photographs of all failures can be found in Appendix A below.

Notes on Dye & Pry Testing in this Project:

The Dye and Pry test method is intended for BGA type components. In this instance, we have adapted this analysis method for leaded and QFN package types. This presented the following issues:

- Considerable difficulty was experienced in removing components from the board. As described above, shims where glued to the tops of the components to provide sufficient leverage points to then pry the component loose. In many cases, this process had to be repeated two, or even three times before the component was successfully removed from the board.
- Another issue arose regarding the use of shims. In gluing the shim to the top of the component, it was not always possible to control the flow of the glue. In some cases it did flow over the leads further adhering the part to the board. Not only did this make the removal of the component from the board more difficult, it also meant that the fracture may not have occurred at the weakest point of the solder joint. All attempts where made to minimize this effect.

5.2 Cross Sectioning

Of the 15 components that were cross sectioned, there were three which experienced electrical failure during drop testing: board 84 U14 (figure 11), board 85 U57 (figure 14), and board 86 U15 (figures 12 and 13). The three components where cross-sectioned at the failing pin to evaluate the failure. The remaining components, those which experienced no electrical failures were cross-sectioned at a corner since based on dye and pry analysis, this is the most likely area for mechanical failures to occur.

board	Component									
	CLCC-20	PDIP-20			QFN-20		TQFP-144			TSOP-50
60							U34**			
81					U15*					
82						U27*		U57		
83		U8**				U27**				
84	U14									U25**
85								U57*	U58	U25*
86		U8*	U30		U15**					
87				U38						

Table 5: Cross-Sectioning Observations

** represents one rework performed*
*** represents two reworks performed*
Components that are underlined represent electrical failure which occurred during the drop test

Based on this limited number of cross sectioned samples, there does not appear to be a correlation between the electrical or mechanical failures and the number of rework cycles which a particular component underwent.

All three electrical failures were clearly evident through cross sectioning. Boards 84 U14 (figure 11) and 86 U15 (figure 12) showed significant pad cratering as well as broken traces. Board 85 U57 (figure 14) showed complete cracking of the solder joint. In addition to pad cratering, board 86 U15 (figure 13) showed evidence of partial cracking in the bulk solder.

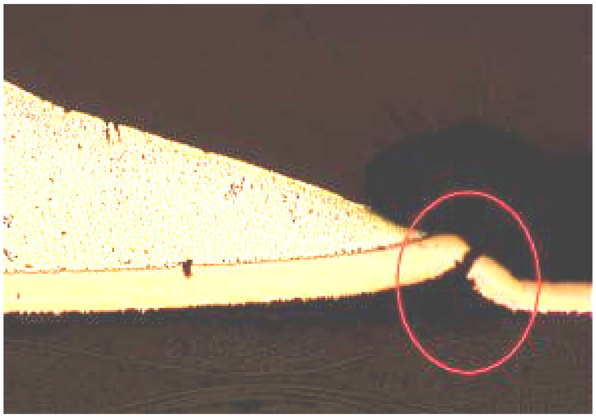


Figure 11: board 84, U14, pin 18, 100x

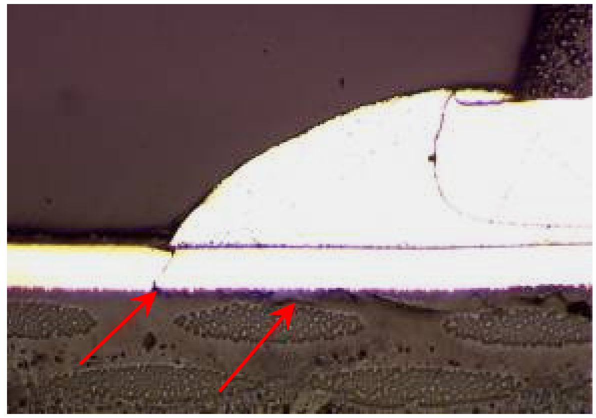


Figure 12: board 86, U15, pin 7, 100x

Both U14 shown in figure 11 and U15 shown in figure 12 show a broken trace which can explain the corresponding electrical failure observed with these two parts. Records from the drop test show that these parts failed after 3 and 18 drops respectively. Board 86, U15 also exhibits pad cratering as indicated by the arrows.

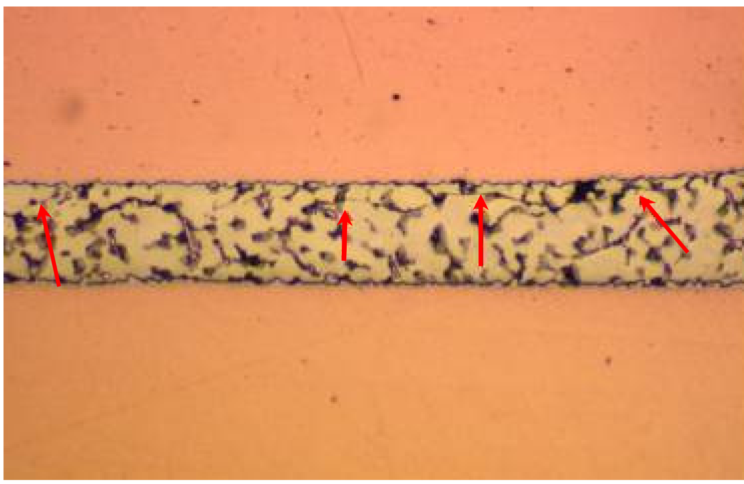


Figure 13: board 86, U15, pin 19, 400x

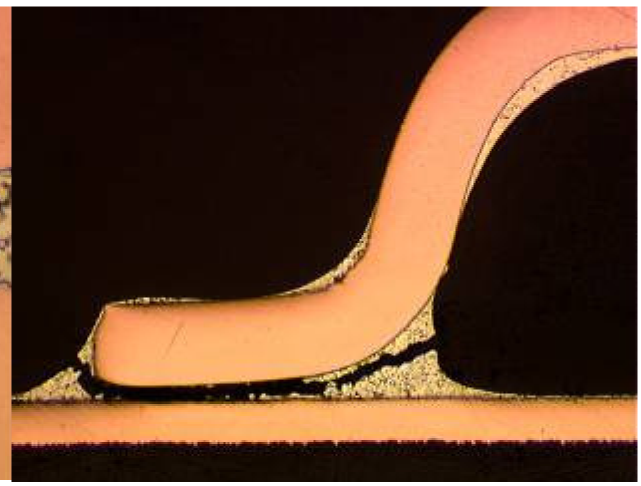


Figure 14: board 85, U57, pin 43, 100x

Figure 13 and 14 illustrate cracking that occurred within the bulk solder, although to greatly differing extents. Both components failed electrically, however board 86, U15 failed at another location then illustrated in figure 13. While there is cracking through the solder, it would not cause the part to fail electrically. Board 85, U57 on the other had shows a complete crack and failure.

No other electrical failures were detected during drop testing, however mechanical failures in the form of pad cratering was seen on other solder joints. Board 81, U15, pin 10 (figure 15) provides a good illustration of this type of mechanical failures.

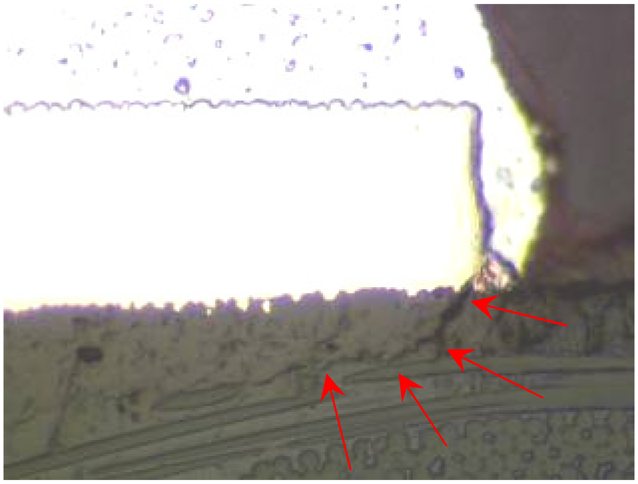


Figure 15: board 81, U15, pin 10, 400x
Pin 10 shows a typical example of pad cratering that was observed, even in the absence of an electrical failure.

None of the PDIP-20s showed any defects related to the drop test.

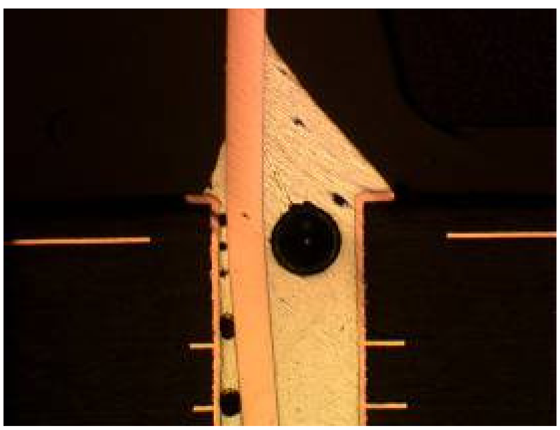


Figure 16: board 87, U38, pin 10, 25x

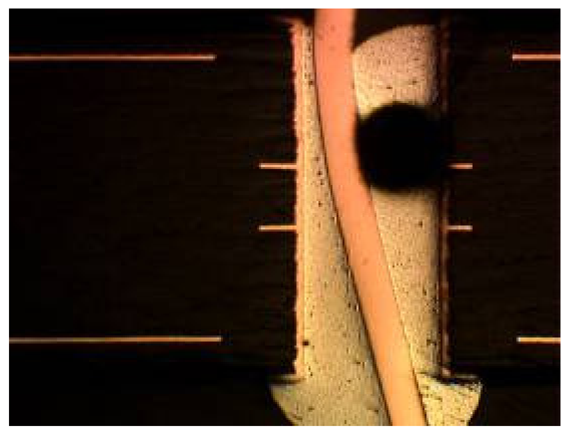


Figure 17: board 86, U8, pin 20, 25x

6. SUMMARY

A set of 8 Crane/Nasa-DoD drop test vehicles were submitted to Celestica's Performance Innovation Laboratories for physical failure analysis. The samples were SMT assembled with Pb-free solder. A subset of the leaded components was then hand soldered (reworked) with SnPb solder. After drop testing only three of the leaded components had electrical failures, one was a non-reworked, one 1x reworked, and one part was 2x reworked. All Pb-free PBGAs (non-reworked) electrically failed by 20 drops at 500G. Twenty-three leaded components from various cards were selected by the customer for failure analysis and subjected to dye & pry testing. None of the components selected for dye & pry testing had electrical failures. Ten out of the 23 components that were dye and pry'd showed signs of mechanical fracture. Most fractures were in the laminate under the pad; pad cratering. Only two out of the 23 components showed signs of solder joint fractures. Based on the 23 components selected for dye & pry, there is no correlation between the number of reworks and the amount of mechanical damage. As well, this sample set shows no difference in drop test performance between SnPb and Pb-free solder.

Fifteen components were also selected for cross-sectioning, three of which were electrical failures after drop testing. Five out of the 15 cross-sectioned joints were found to have some level of mechanical damage, pad cratering. For two of the electrically failing parts the root cause of the electrical failure was a trace break due to pad cratering. The other part failed due to solder fatigue fracture. The remaining 2 samples had pad cratering which did not sever the copper trace.

In this study, a total of three components were found to have some mechanical failure in the solder, one of these resulted in an actual electrical failure. In all of these cases, the solder used was SnPb reworked. No solder failures were observed in the lead free, non-reworked components. All mechanical failures in the Pb-free soldered components were the result of pad cratering.

The location of the electrical failures is illustrated in figure 18.

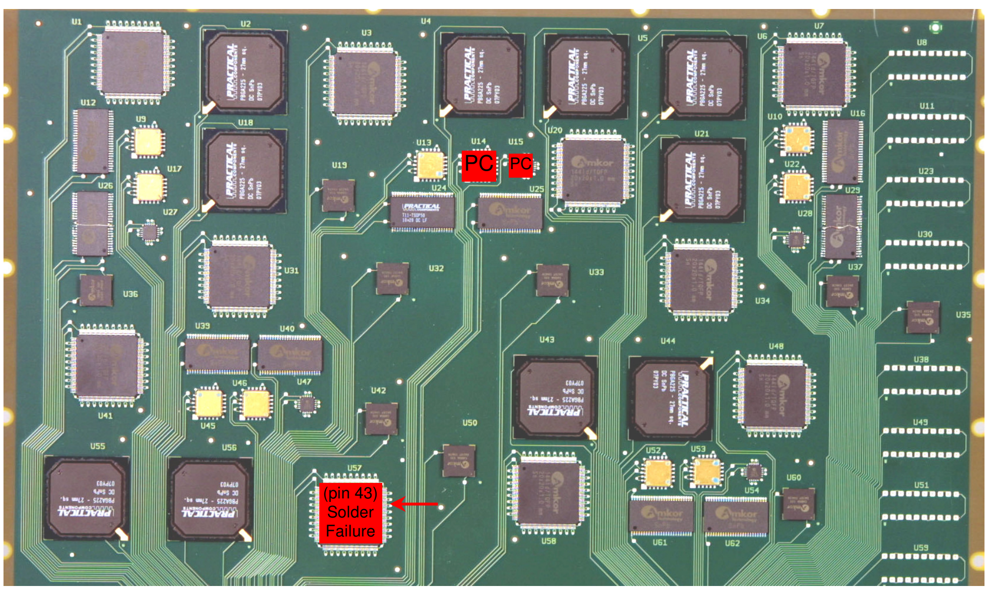


Figure 18: Location of Electrical Failures

APPENDIX A: Dye & Pry Images

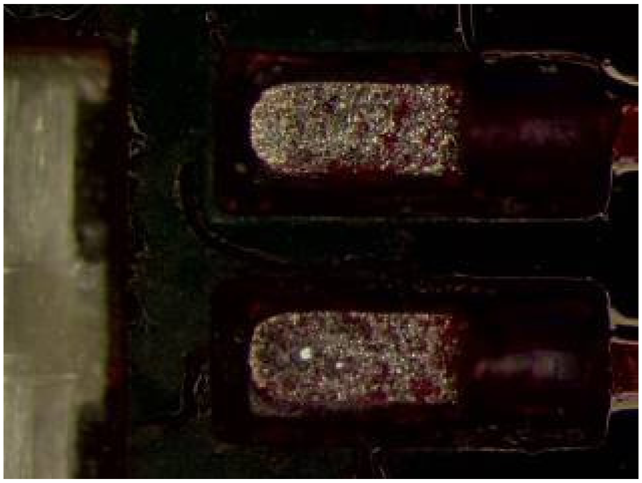


Figure 19: board 60, U15, pins 6-7, board side


Figure 20: board 60, U15, pins 6-7, comp. side

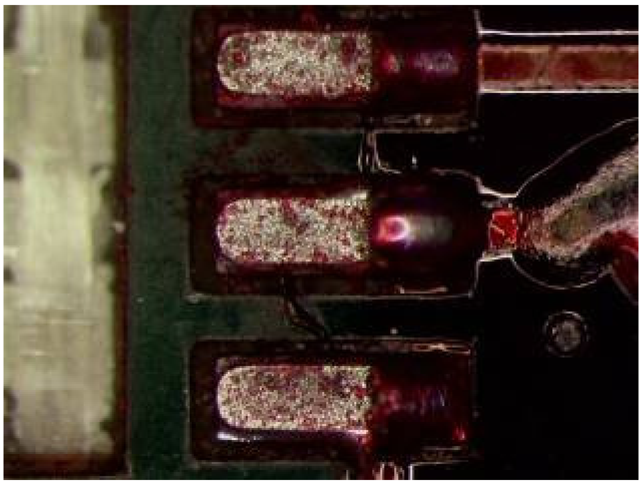


Figure 21: board 60, U15, pins 8-10, board side


Figure 22: board 60, U15, pins 8-10, comp. side


Figure 23: board 60, U15, pin 11, board side


Figure 16: board 60, U15, pins 11-12, comp. side

Figure 24: board 60, U15, pins 16-17 board side

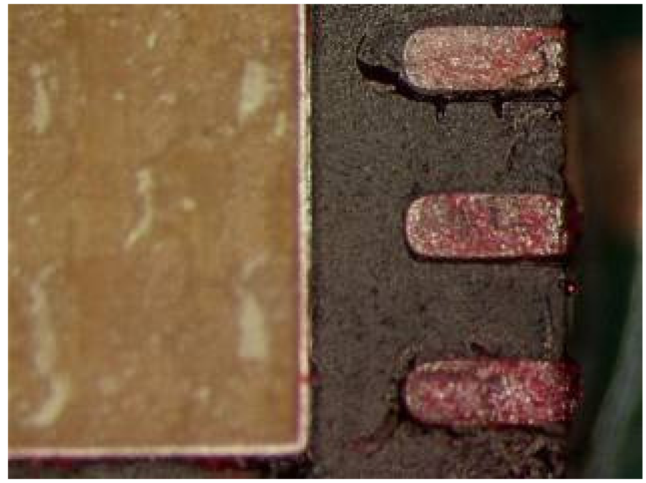


Figure 25: board 60, U15, pins 16-18 comp. side

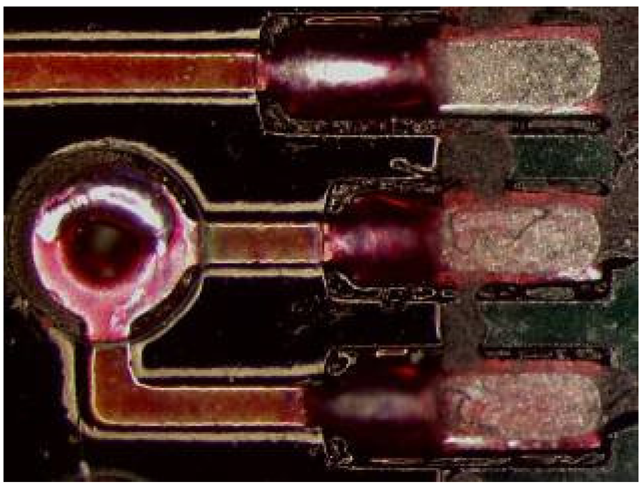


Figure 26: board 60, U15, pins 18-20, board side

Figure 27: board 60, U15, pins 19-20, comp. side

Figure 28: board 60, U27, pins 4-5, board side

Figure 29: board 60, U27, pins 4-5, comp. side

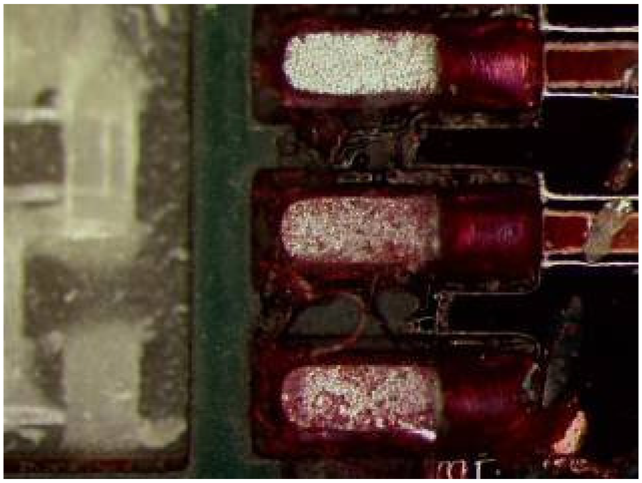


Figure 30: board 60, U27, pins 8-10, board side


Figure 31: board 60, U27, pins 9-10, comp. side

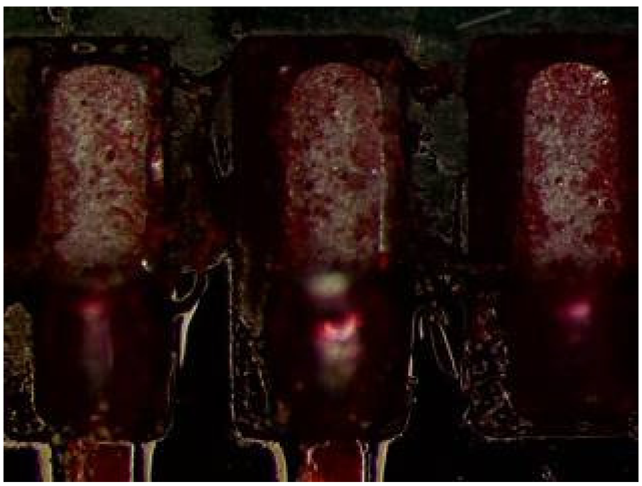


Figure 32: board 60, U27, pins 11-13, board side


Figure 33: board 60, U27, pins 11-13, comp. side


Figure 34: board 60, U27, pins 14-15, board side


Figure 35: board 60, U27, pins 14-15, comp. side

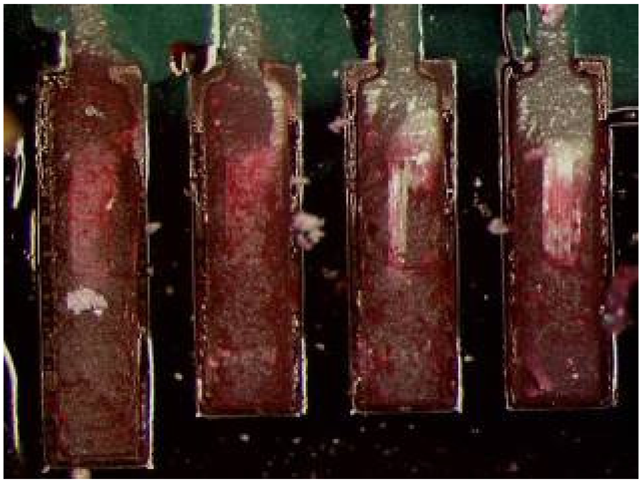


Figure 36: board 81, U25, pins 1-4, board side

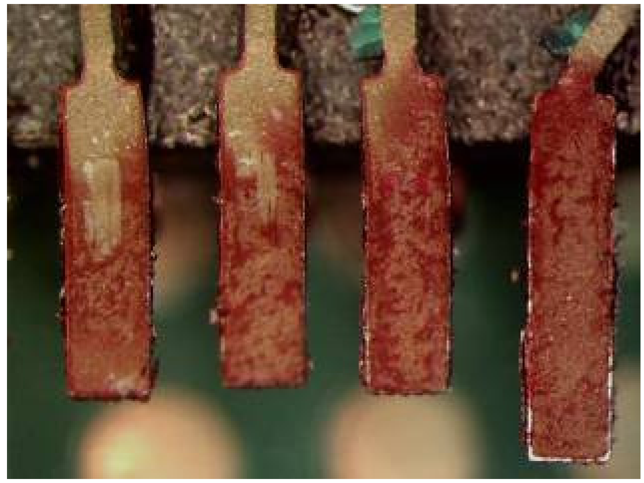


Figure 37: board 81, U25, pins 1-4, comp. side

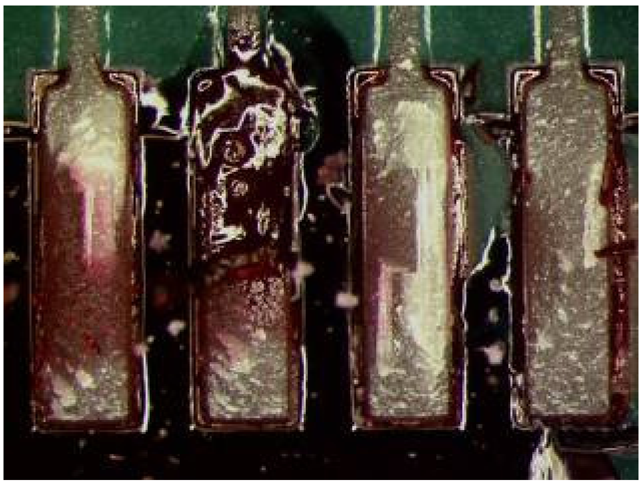


Figure 38: board 81, U25, pins 5-8 board side

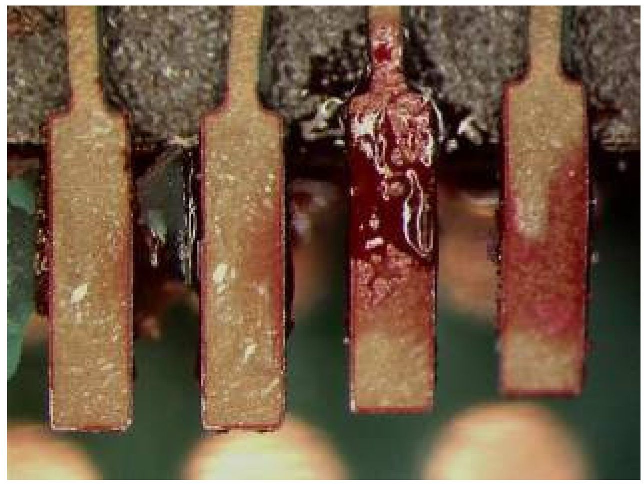


Figure 39: board 81, U25, pins 5-8 comp. side

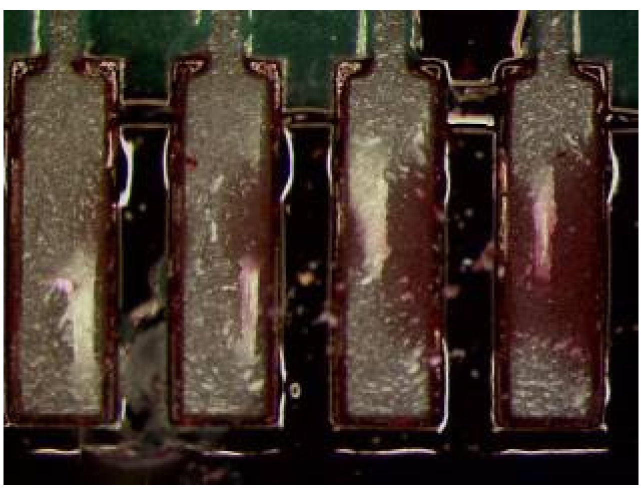


Figure 40: board 81, U25, pins 18-21, board side

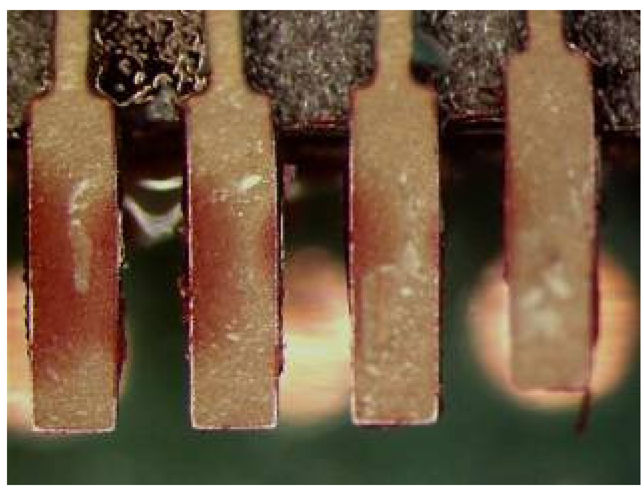


Figure 41: board 81, U25, pins 18-21, comp. side

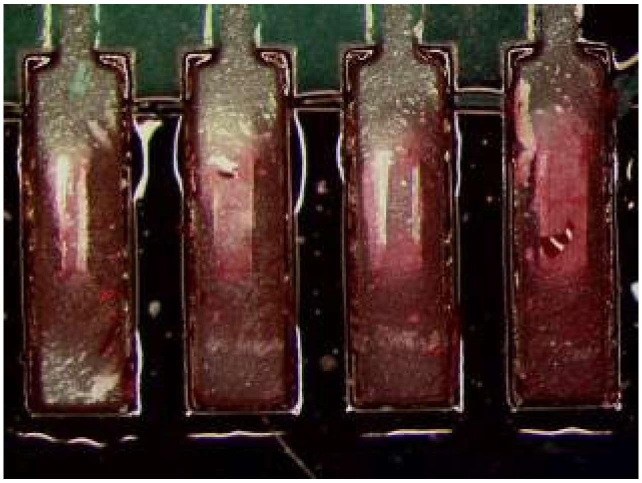


Figure 42: board 81, U25, pins 22-25, board side

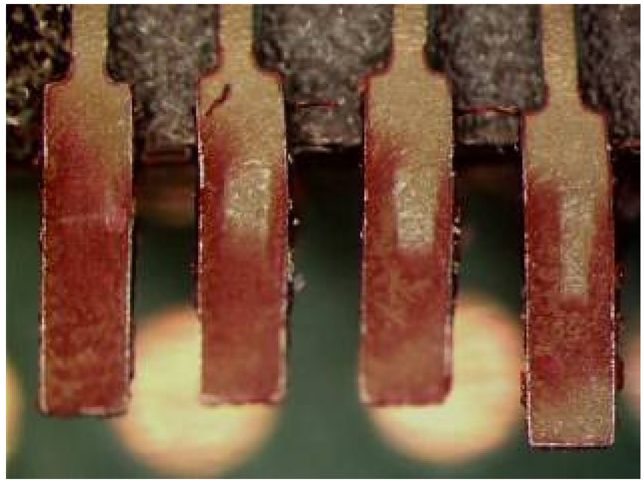


Figure 43: board 81, U25, pins 22-25, comp. side

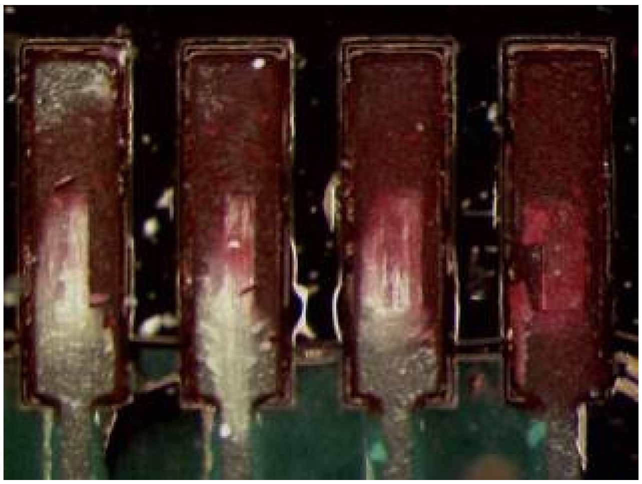


Figure 44: board 81, U25, pins 26-29, board side

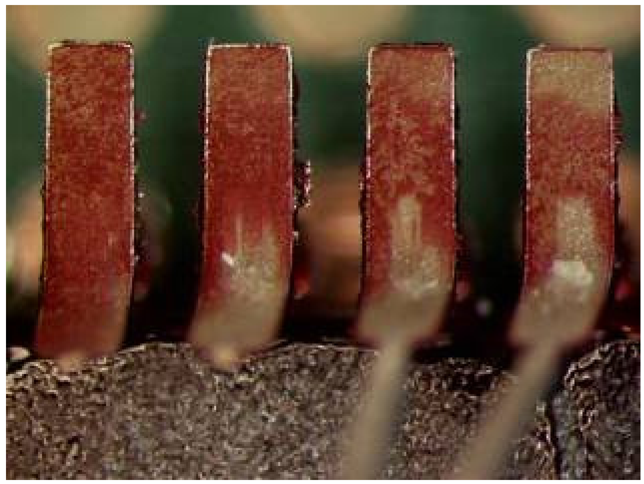


Figure 45: board 81, U25, pins 26-29, comp. side

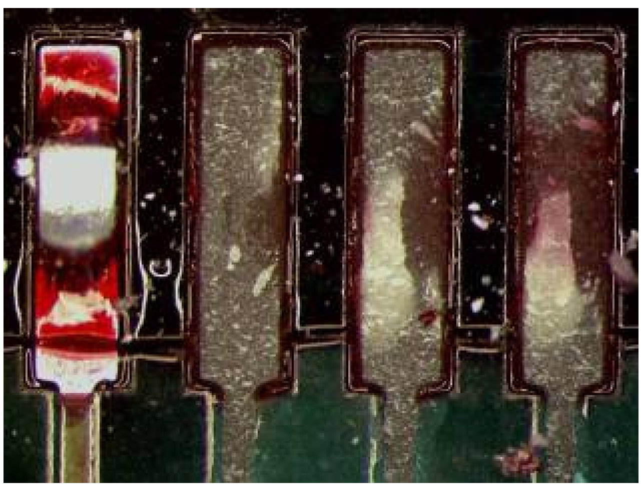


Figure 46: board 81, U25, pins 30-33, board side

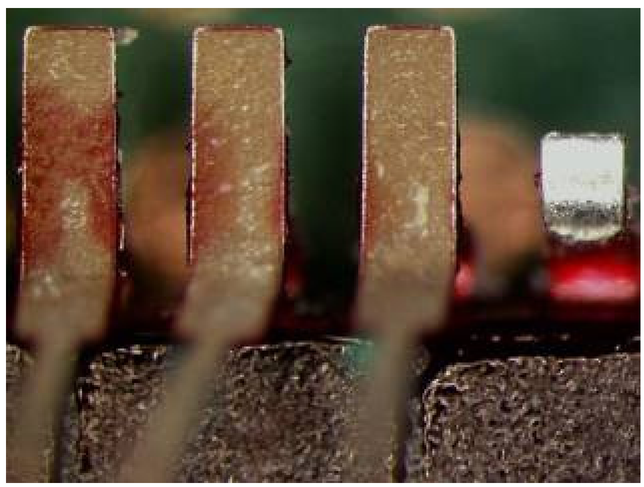


Figure 47: board 81, U25, pins 30-33, comp. side

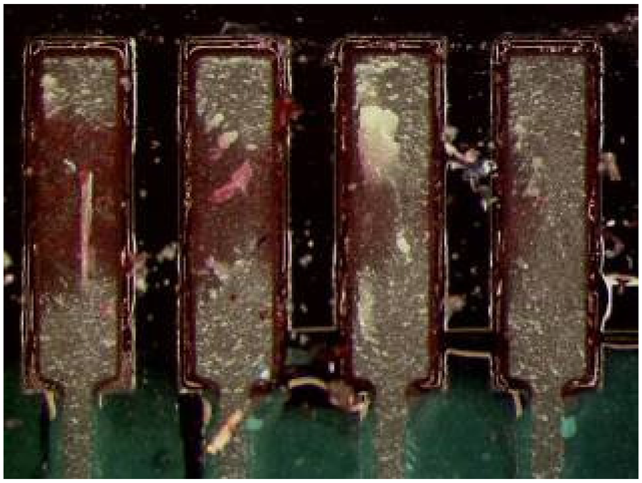


Figure 48: board 81, U25, pins 43-46, board side

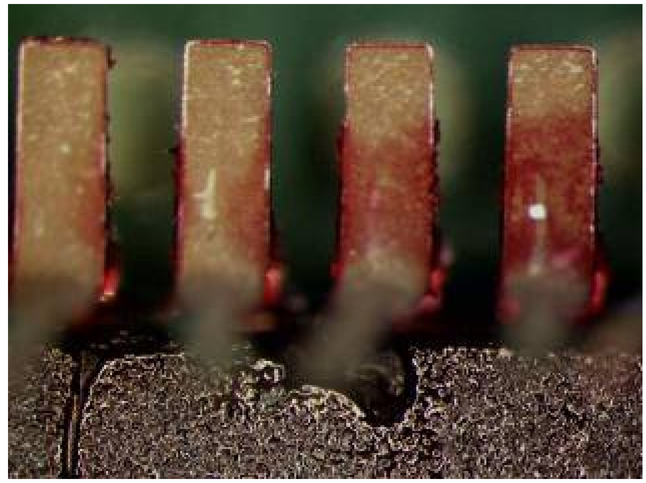


Figure 49: board 81, U25, pins 43-46, comp. side

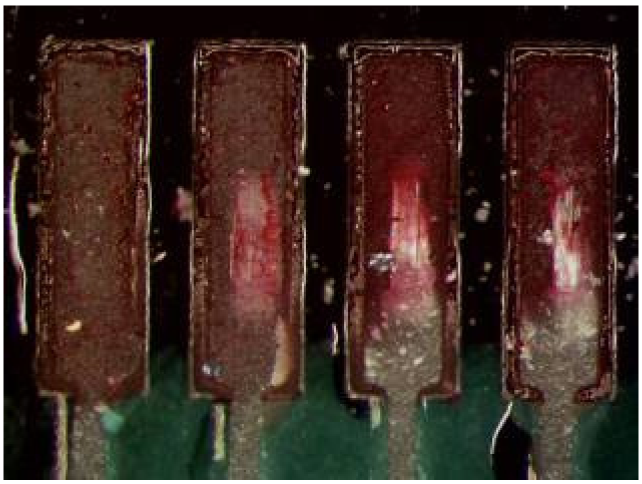


Figure 50: board 81, U25, pins 47-50, board side

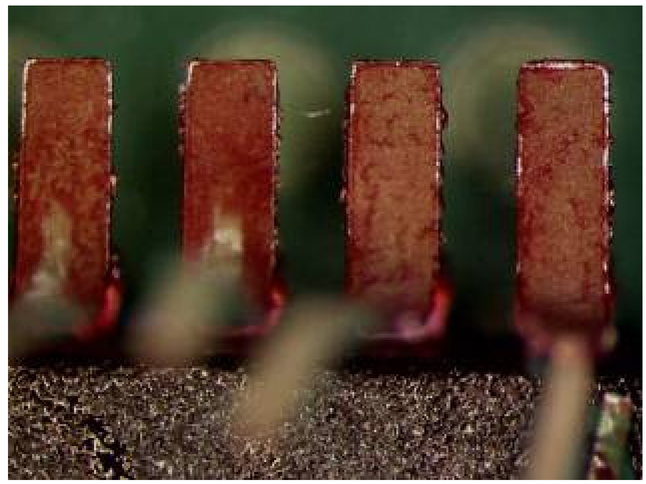


Figure 51: board 81, U25, pins 47-50, comp. side

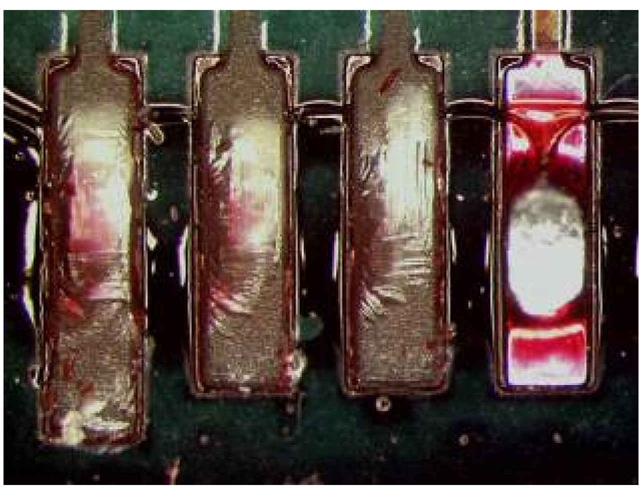


Figure 52: board 83, U25, pins 1-4, board side

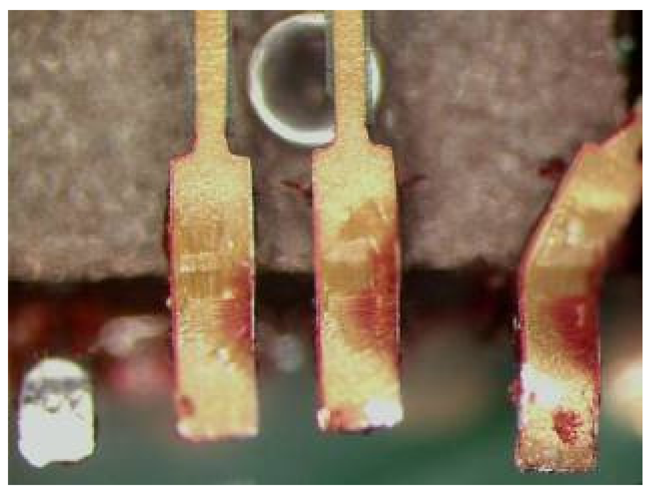


Figure 53: board 83, U25, pins 1-4, comp. side

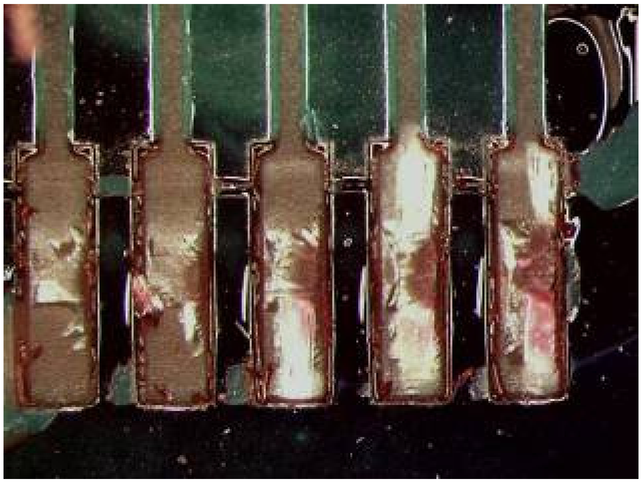


Figure 54: board 83, U25, pins 21-25, board side

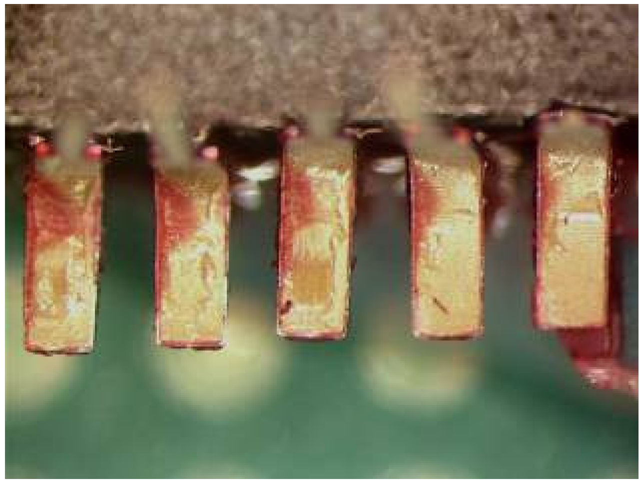


Figure 55: board 83, U25, pins 21-25, comp. side

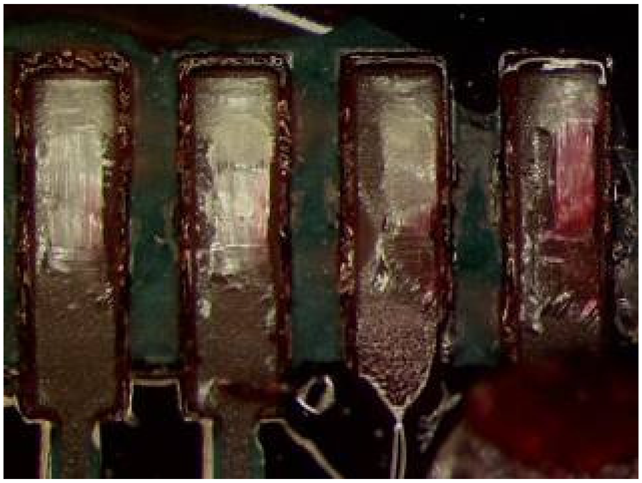


Figure 56: board 83, U25, pins 26-30, board side

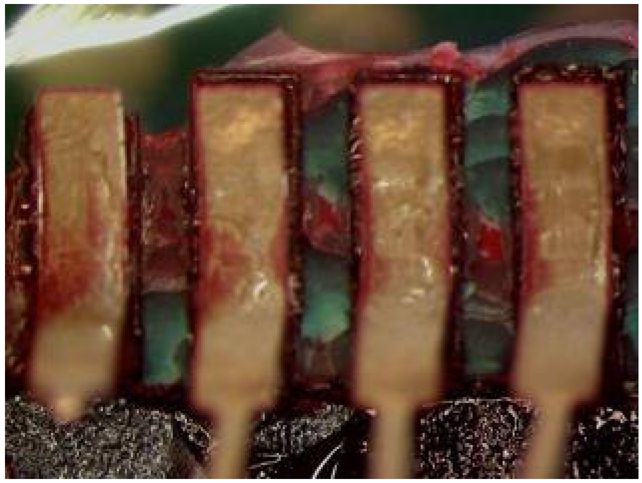


Figure 57: board 83, U25, pins 26-30, comp. side

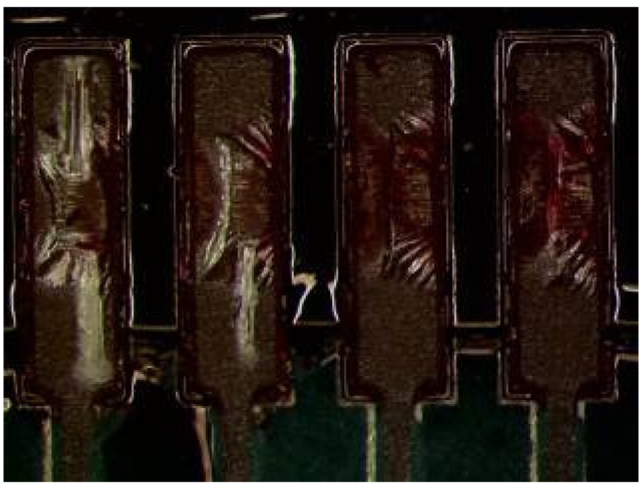


Figure 58: board 83, U25, pins 43-46, board side

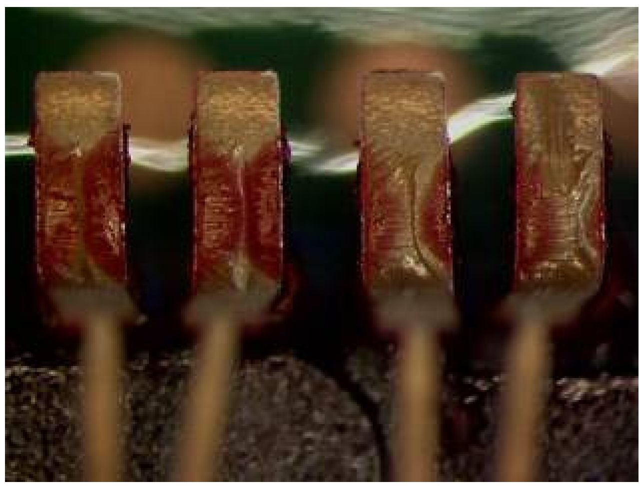


Figure 59: board 83, U25, pins 43-46, comp. side

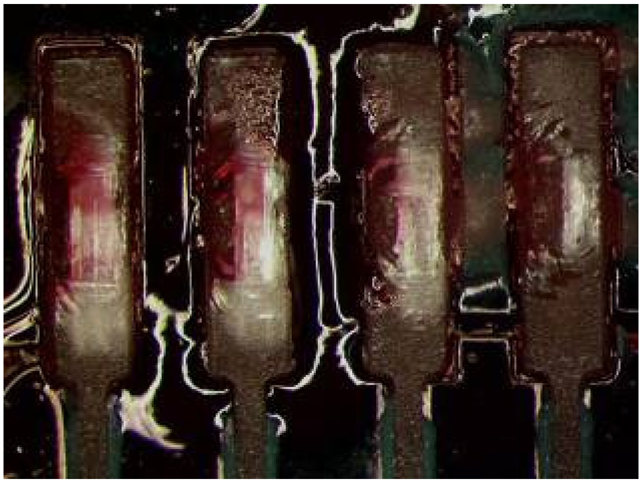


Figure 60: board 83, U25, pins 47-50, board side

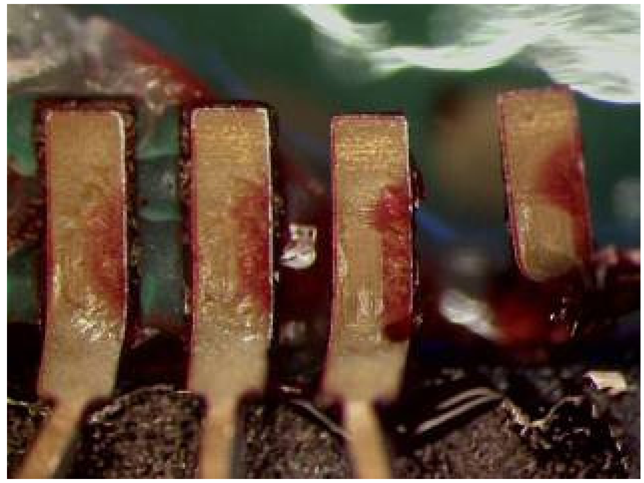


Figure 61: board 83, U25, pins 47-50, comp. side


Figure 62: board 84, U25, pins 9, 10, board side


Figure 63: board 84, U25, pins 9, 10, comp. side

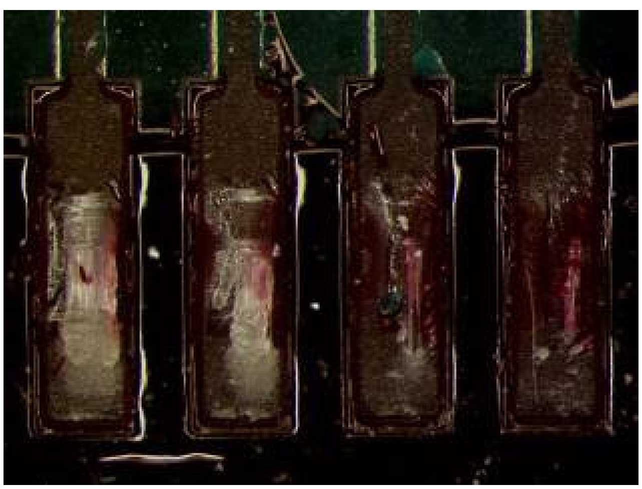


Figure 64: board 86, U25, pins 18-21, board side

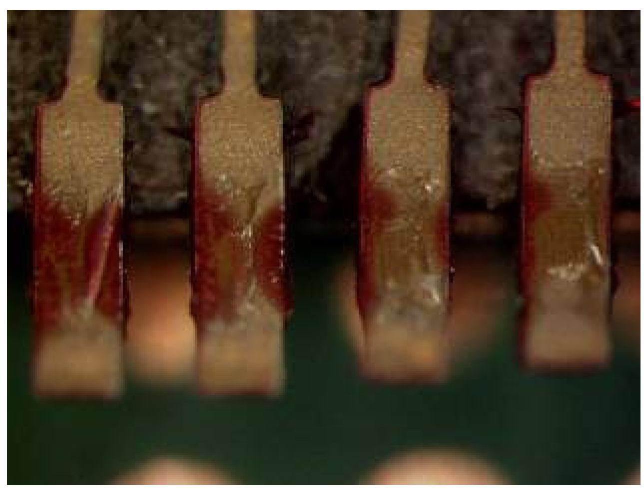


Figure 65: board 86, U25, pins 18-21, comp. side

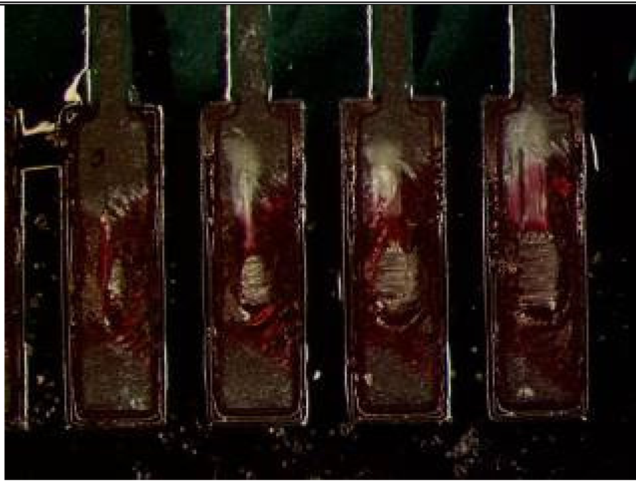


Figure 66: board 86, U25, pins 22-25, board side

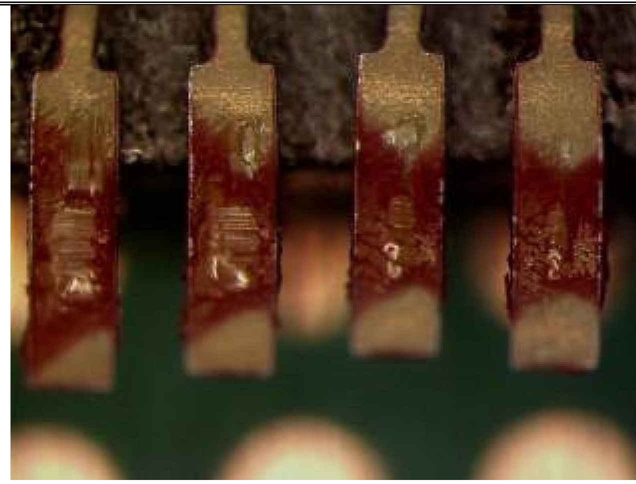


Figure 67: board 86, U25, pins 22-25, comp. side

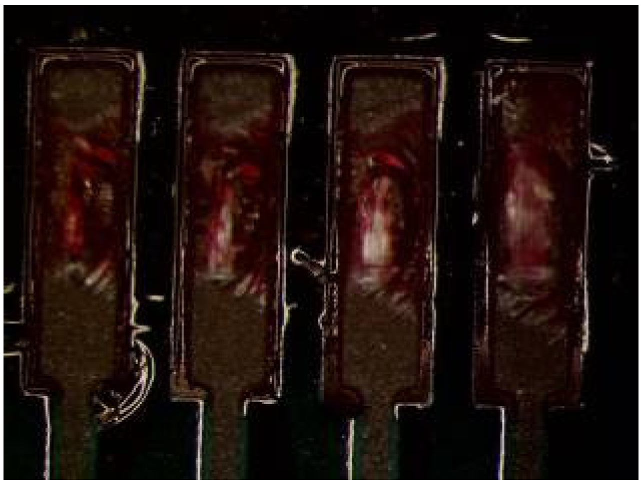


Figure 68: board 86, U25, pins 26-29, board side

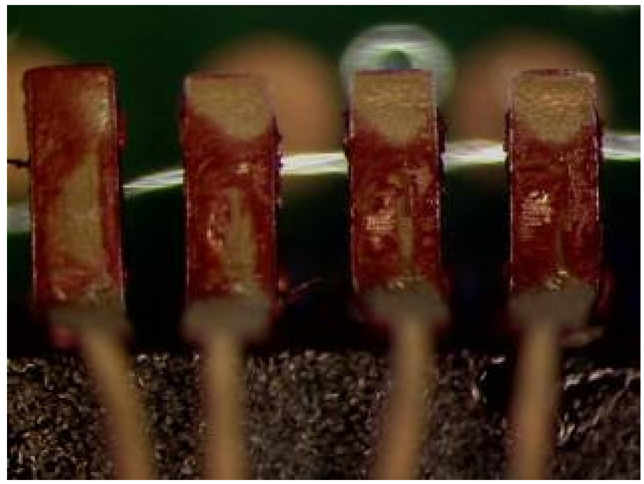


Figure 69: board 86, U25, pins 26-29, comp. side

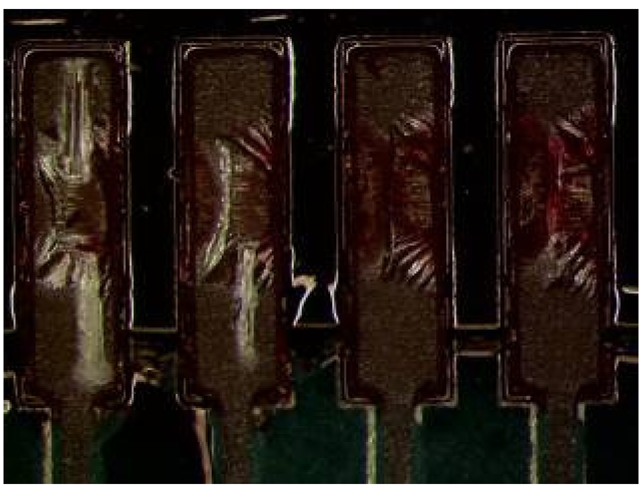


Figure 70: board 86, U25, pins 30-33, board side

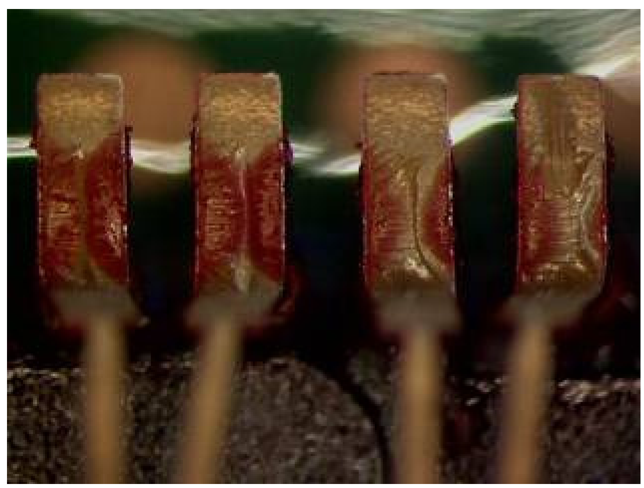


Figure 71: board 86, U25, pins 30-33, comp. side

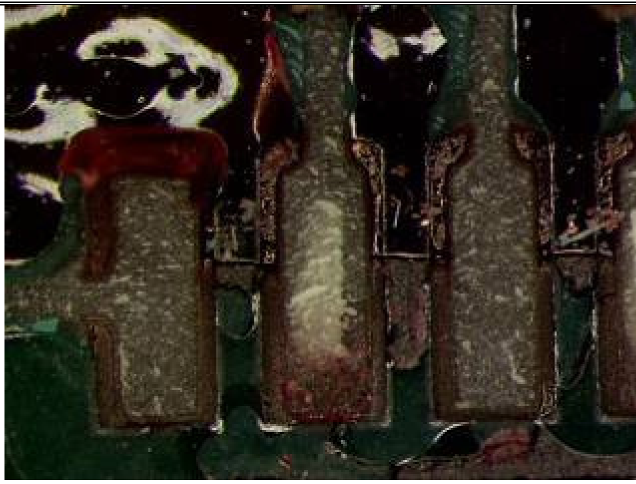


Figure 72: board 87, U15, pins 1-3, board side

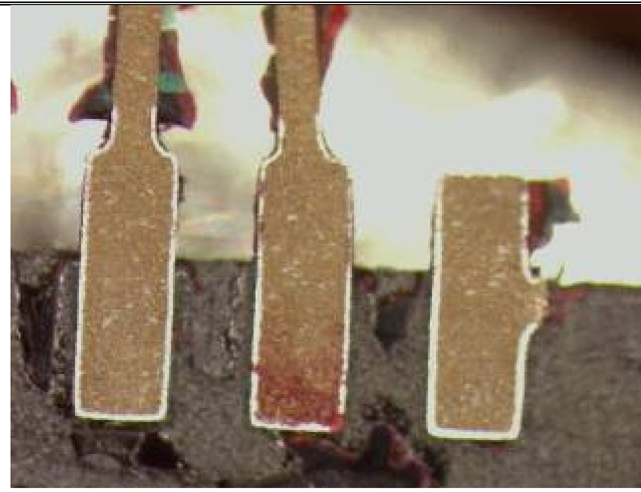


Figure 73: board 87, U15, pins 1-3, comp. side


Figure 74: board 87, U25, pins 1-4, board side

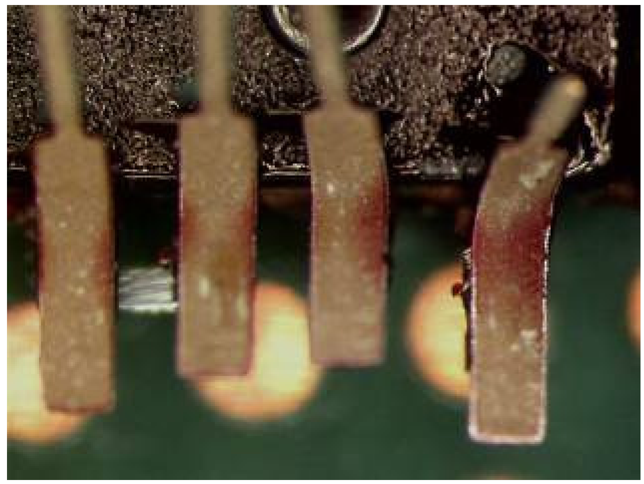


Figure 75: board 87, U25, pins 1-4, comp. side

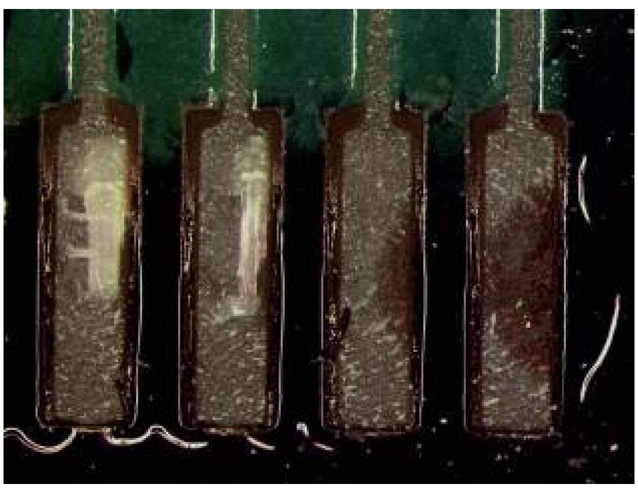


Figure 76: board 87, U25, pins 22-25, board side

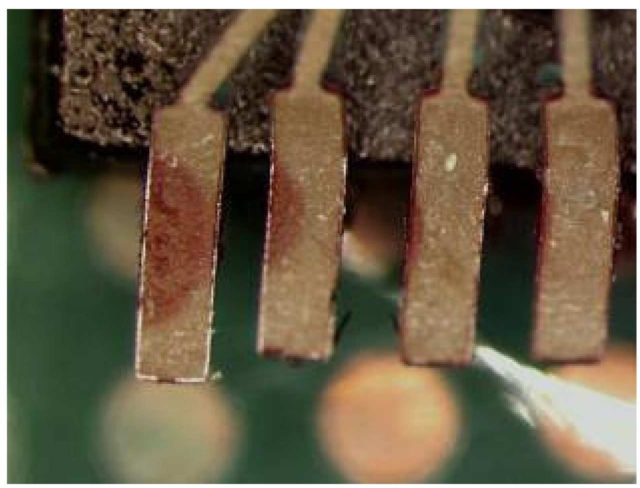


Figure 77: board 87, U25, pins 22-25, comp. side

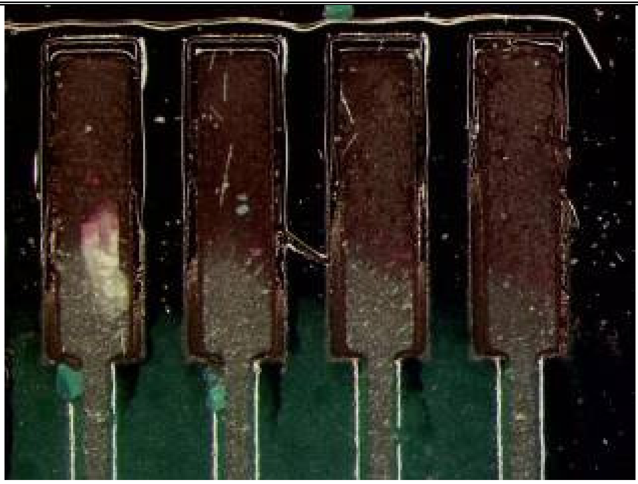


Figure 78: board 87, U25, pins 26-29 board side

Figure 80: board 87, U25, pins 30-33, board side

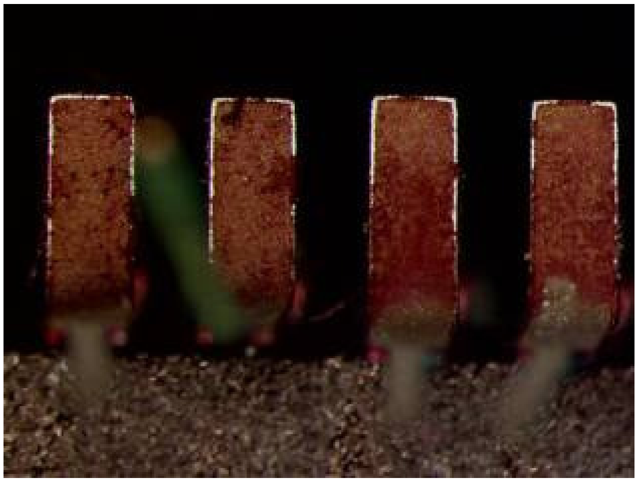


Figure 79: board 87, U25, pins 26-29 comp. side

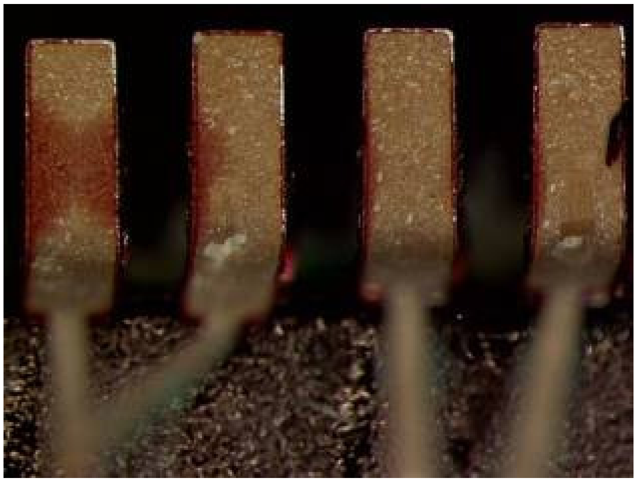


Figure 81: board 87, U25, pins 30-33, comp. side

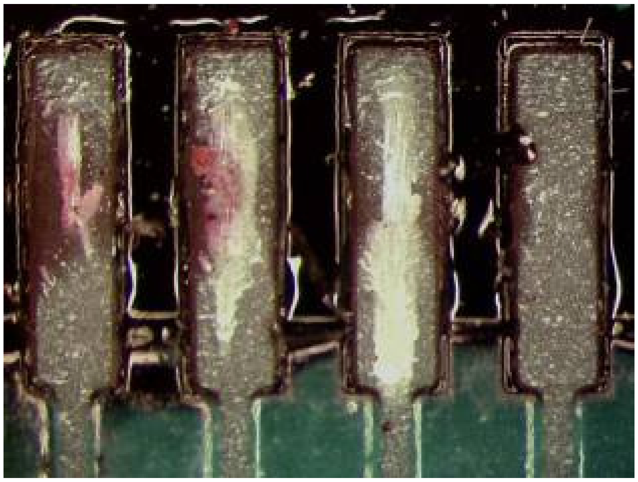


Figure 82: board 87, U25, pins 47-50, board side

Figure 83: board 87, U25, pins 49-50, comp. side

APPENDIX B: Cross Section Images

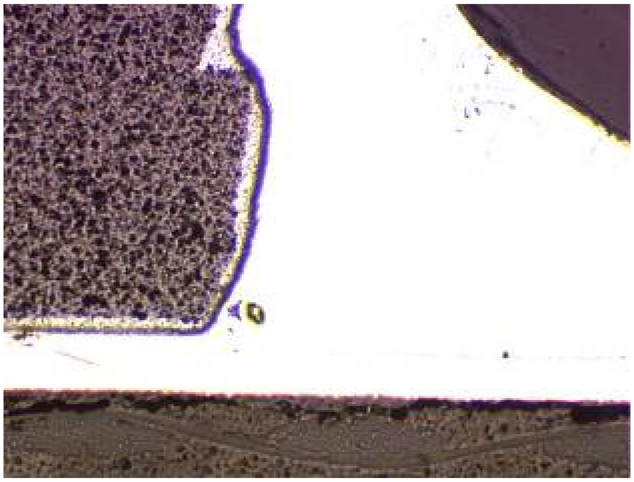


Figure 84: board 84, U14, pin 8, 100x

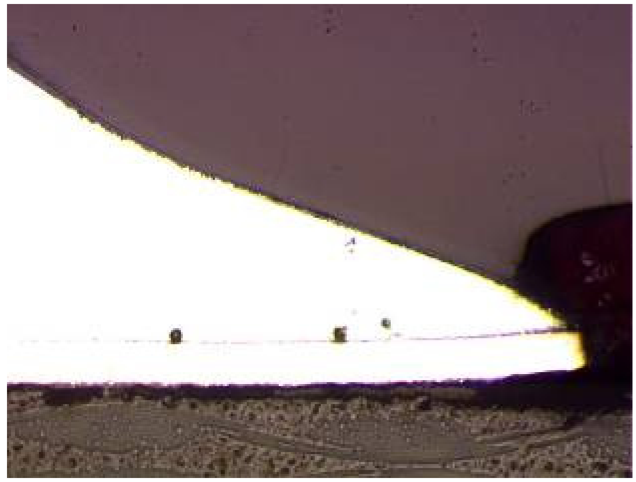


Figure 86: board 84, U14, pin 8, 100x, 3

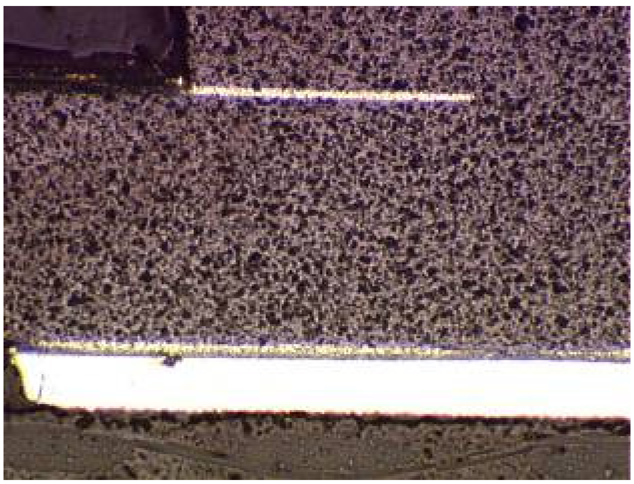


Figure 85: board 84, U14, pin 8, 100x, 2

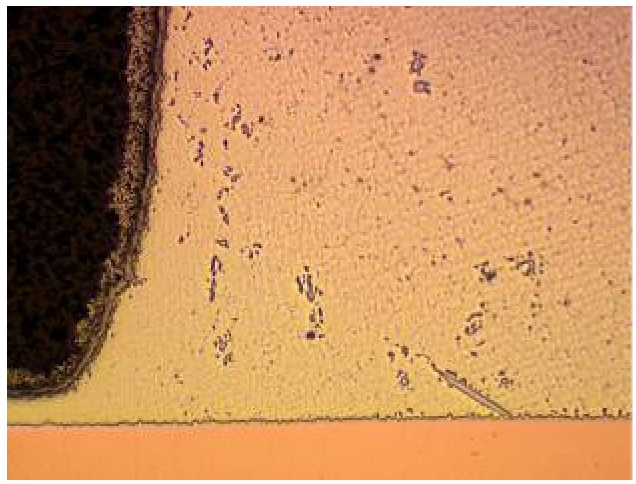


Figure 87: board 84, U14, pin 8, 200x

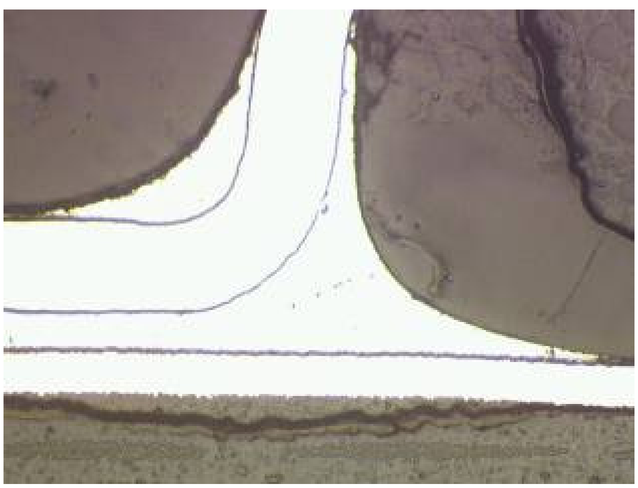


Figure 88: board 84, U25, pin 25, 100x

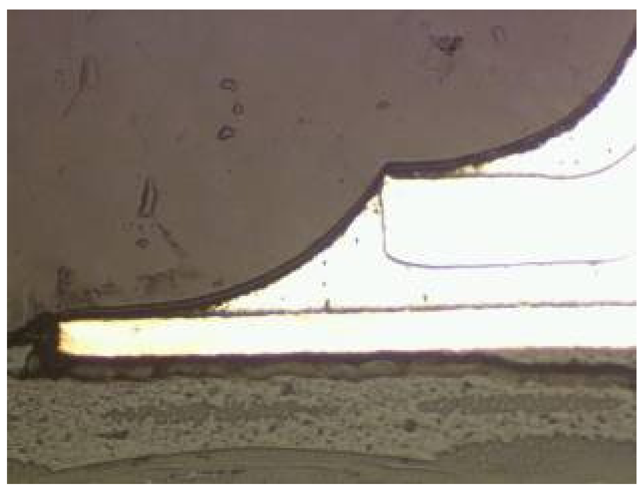


Figure 89: board 84, U25, pin 25, 100x, 2

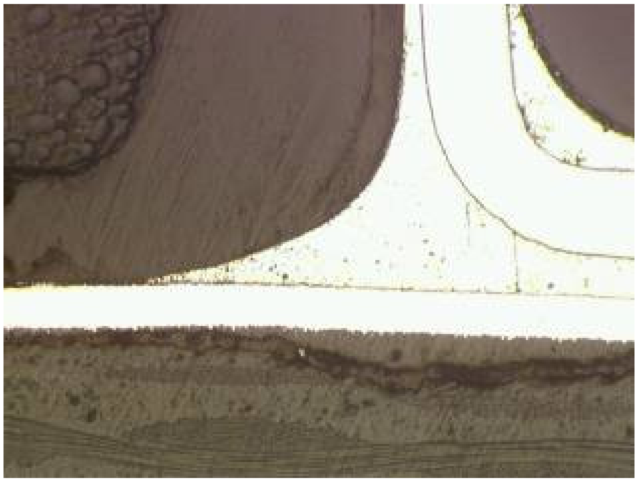


Figure 90: board 84, U25, pin 26, 100x

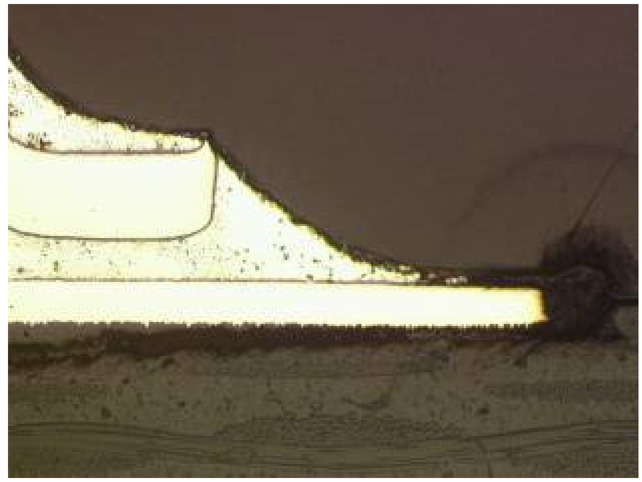


Figure 91: board 84, U25, pin 26, 100x, 2

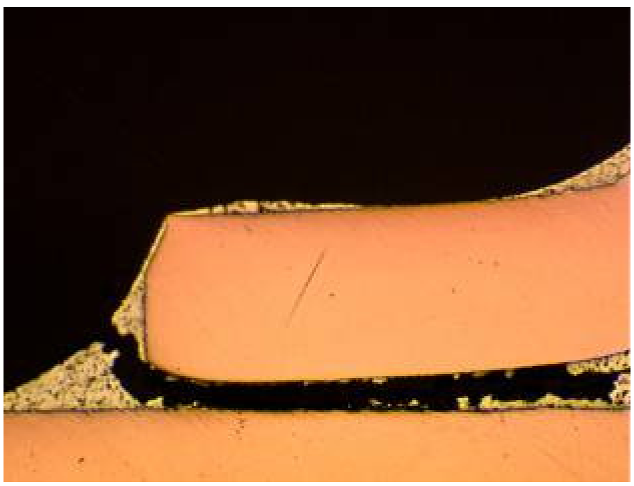


Figure 92: board 85, U57, pin 43, 200x

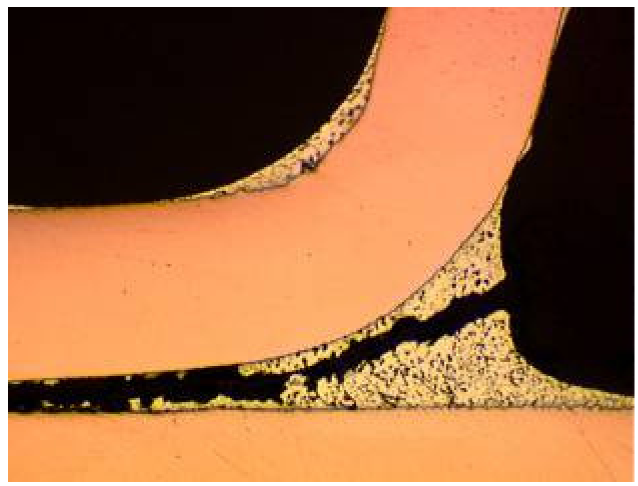


Figure 93: board 85, U57, pin 43, 200x, 2

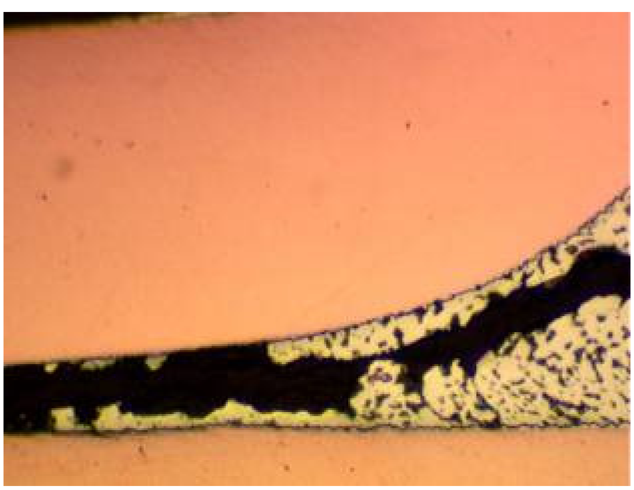


Figure 94: board 85, U57, pin 43, 400x

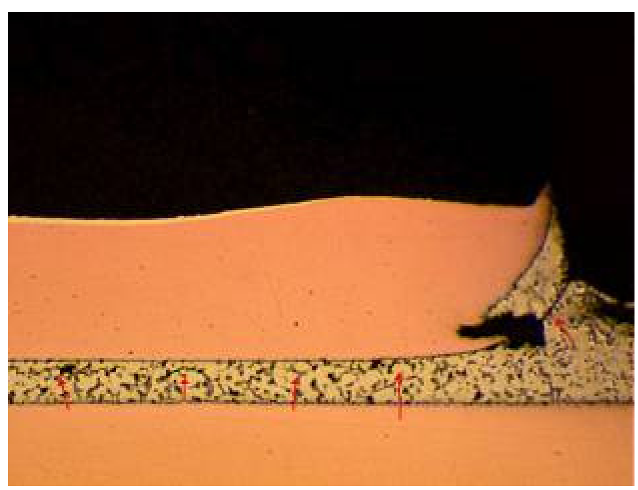


Figure 95: board 86, U15, pin 19, 200x

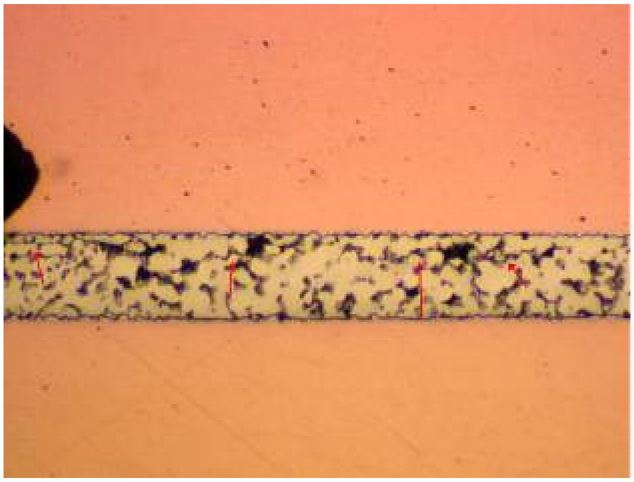


Figure 96: board 86, U15, pin 19, 400x

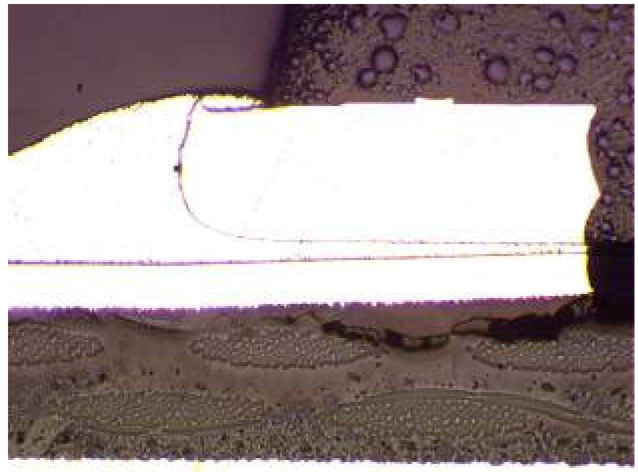


Figure 97: board 86, U15, pin 7, 100x

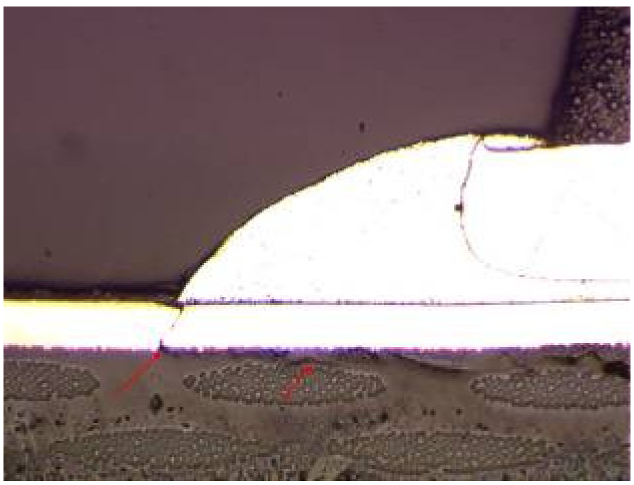


Figure 98: board 86, U15, pin 7, 100x, 2

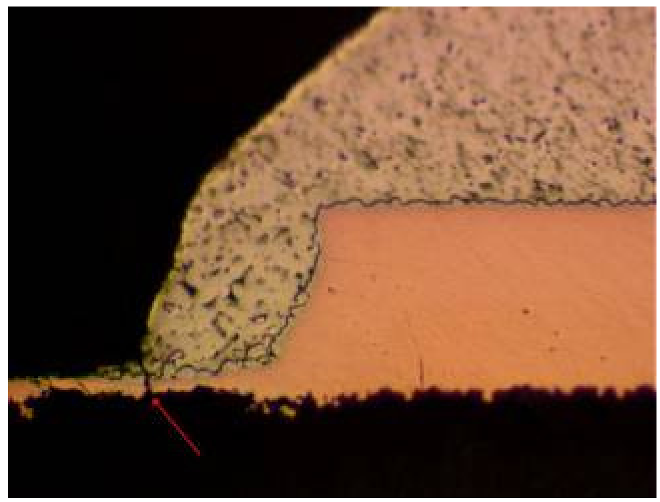


Figure 99: board 86, U15, pin 7, 200x

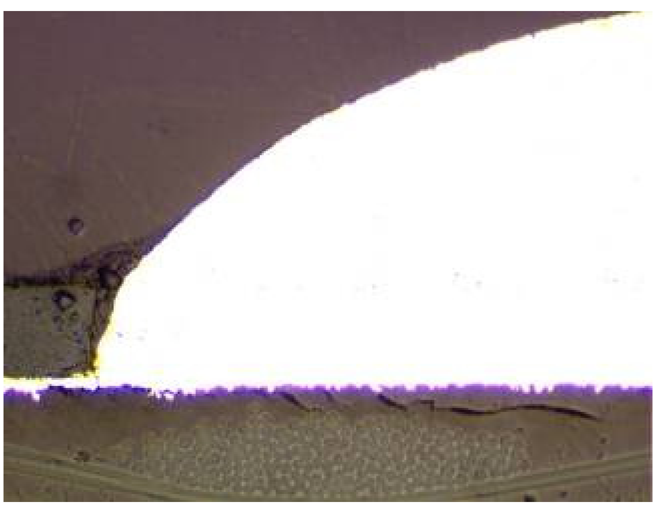


Figure 100: board 86, U15, pin 7, 200x, 2

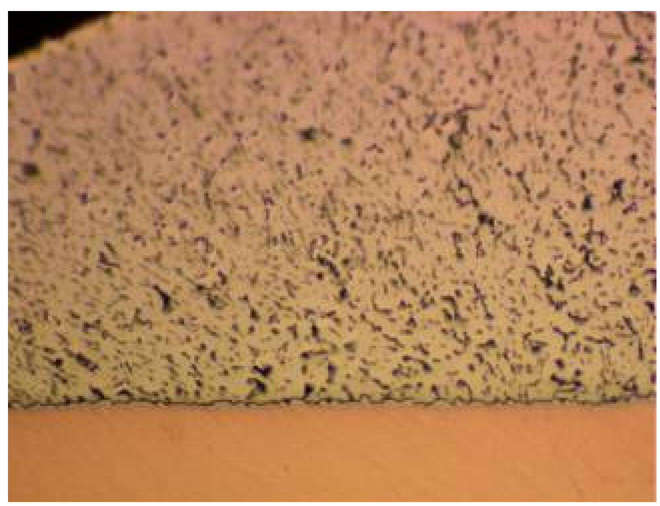


Figure 101: board 86, U15, pin 7, 400x